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THE BEHAVIOUR OF A COMPRESSION IGNITION ENGINE UNDER THE INFLUENCE OF DIESEL AND MICROALGAE BIODIESEL BLENDS

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ABSTRACT

In the days to come Algae is going to be everything. Wonders would be created using algae. Scientists predict that, from the oxygen that we inhale to the electricity that we use, algae would be the source of energy in the future. Researchers said that, Algae could be a possible answer to the problems that the world would face in the future. Now biodiesel produced from algae is getting ready to address the fuel crisis. The present work deals with the utilization of Microalgae biodiesel to evaluate the performance, emission and combustion characteristics of compression ignition engine. Microalgae methyl ester (MME) was produced from crude microalgae oil derived from chlorella vulgaries using transesterification process. Various blends were prepared and nominated as MME10D90, MME20D80 and MME30D70. Experiment was conducted on single cylinder four stroke diesel engine and the experimental results were revealed that, at full load condition with MME30D70 the BTE and BSFC were improved by 14.09% and 7.69% respectively, CO and UHC emissions were reduced by 71.97%, and 15.56% respectively but, NO_X was increased by 11.58% as compared with diesel fuel and smoke was reduced by 10.36%.

***KEYWORDS:** Algae, Chlorella Vulgaries, Microalgae Methyl Ester & Transesterification*

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Original Article

INTRODUCTION

The era of oil is not yet over, with the United States accounting for 80% of the increase in global oil supply to 2025 and maintaining near – term downward pressure on prices, the world's consumers are not yet ready to say goodbye to the era of oil [1]. Renewable energy is a promising alternative solution in the near future because it is clean and environmentally safe. Biofuels are expected to reduce dependence on imported petroleum with its associated political and economic vulnerability, reduce green house gas emissions and other pollutants and revitalize the economy by increasing demand and prices for agricultural products. Approximately half of the global energy supply will come from renewable in 2040 [2]. Biomass is currently the most used renewable energy source and will continue to be so in the foreseeable future. It has been estimated that known petroleum reserves will be depleted in less than 50 years at the present rate of consumption [3]. We can get fuel from fruit, from that shrub by the road side or from apples, weeds, sawdust almost everything ; there is fuel in every bit of vegetable matter that can be fermented. There is enough alcohol in one year's yield of a hectare of potatos to drive the machinery necessary to cultivate the field for a hundred years. And it remains for someone to find out how this fuel can be produced commercially better fuel at a cheaper price than we know now said by Henry Ford in 1925.

Microalgae are prokaryotic or eukaryotic photosynthetic microorganisms that can grow rapidly and live in harsh conditions due to their unicellular or simple multicellular structure. Examples of prokaryotic microorganisms are Cyanobacteria (Cyanophyceae) and eukaryotic microalgae are for example green algae (Chlorophyta) and diatoms (Bacillariophyta) [4]. Microalgae can provide several types of renewable biofuels. These include methane produced by anaerobic digestion of the algal biomass. The idea of using microalgae as source of fuel is not new, but it is now being taken seriously because of the escalating price of petroleum and, more significantly the emerging concern about global warming that is associated with burning fossil fuels [5].

Biodiesel is produced currently from plant and animal oils, but not from microalgae. Biodiesel is a proven fuel, the technology for producing and using biodiesel has been known for more than 50 years [6]. Anoop Singh et al have reported that, third generation biofuels from algal cells grown on non-arable land is the obvious answer to the food – fuel competition [7]. A.L. Ahmad et al stated that, Biodiesel resources should focus on feed stocks that do not compete with food crops, do not lead to land clearing and provide green house–gas reductions. Theoretically microalgae have been shown to be a potential source to produce third generation bio-diesel [8]. Teresa M. Mata et al claimed that, a large number of companies are claiming that they are at the frontline of the technology and will be producing algal biodiesel economically within the next few years [9].

Farouk K. El-Baz et al investigated the effect of algal biodiesel on the Performance and Emission characteristics of diesel engine. The result showed that, biodiesel produced from algae is environmentally friendly [10]. Saddam H. AI-Iwayzy et al conducted an experiment on single cylinder diesel engine using microalgae oil blended with diesel, and results indicated that, the engine emissions such as NO_X, CO, CO_2 and HC were reduced with 20% of blend [11]. Ganesh Nagane et al tested the variable compression ratio diesel engine fuelled with algae biodiesel and diesel blends. The experimental results revealed that, emission characteristics like CO, CO_2 decreased where as NO_X increased with increase in blending ratio [12]. Yusuf Chisti noticed that biodiesel from microalgae seems to be the only renewable biofuel that has the potential to completely displace petroleum derived transport fuels without adversely affecting supply of food and other crop products [13].

M.A. Rahman et al produced biodiesel from microalgae spirulina maxima by employing two step esterification processes [14]. Ayhan Demibras et al stated that, microalgae are the fastest growing plants in the world. Microalgae have much faster growth-rates than terrestrial crops. About 50% of their weight is oil. This lipid oil can be used to make biodiesel for cars, trucks and airplanes. Algal-oil processes into biodiesel as easily as oil derived from land based crops [15]. J. Kuberan et al did experimentation on single cylinder diesel engine powered with Spirulina algae biodiesel and fossil diesel blends. At the end it was concluded that, spirulina algae biodiesel S30 has produced best emission characteristics than pure diesel [16]. S. Karthikeyan et al have investigated the environmental effect of Microalgae Methyl Ester used as alternate fuel blended with diesel in a compression ignition engine. The experimental results reveal that the use of microalgae biodiesel blend with nano additives in diesel engine has exhibited good improvement in performance characteristics and reduction in exhaust emissions [17]. R. Velappan et al have outlined their experimental results using microalgae biodiesel derived from chlorella vulgaris that, the B20 (20% microalgae biodiesel + 80% fossil diesel) blend at injection pressure 210 bar produced considerable change in the performance and emission characteristics of a diesel engine [18]. Ranjan Kumar Bhaogobaty had announced that, endophyte a fungal microorganism have the ability to produce biofuel and represents a promising source of new biofuel in future [19]. Ramon Piloto-Rodriguez et al delineated that, the

impact of the use of biofuels produced from Microalgae to power diesel engines. Biofuels derived from algae can have the lower impact on the environment and the food supply than biofuels produced from crops [20].

Chlorella vulgaris is green eukaryotic microalgae possessing the potential to be used as feed stock for producing biofuel. It can be treated as a good alternative to the current biofuel crops such as soybean, rapeseed etc, as it is more productive and do not compete with food products [7]. It can produce large amount of lipid content, up to 20 times more than crop [21]. It contains lipids 5-40% of the dry mass [22]. And also it contains more quantity of starch which is good enough to produce bio-ethanol. However, biodiesel produced from micro algae is still far from being competitive with fossil fuels due to their high production cost [23].

It is a spherical in shape about 2 to 10 µm in diameter, for its reproduction it requires only carbon dioxide, water, sunlight and a small amount of minerals [24]. Yusuf Chisti reported that, there are three main sources of microalgae (Chlorella sp, Spirulina sp, and Nitzschia sp). The oil contents of these three main sources are 28-32%, 50-77% and 45-47% respectively [5].

This paper deals with the behaviour of compression ignition engine powered with fossil diesel and microalgae methyl ester (MME) blends. Crude microalgae oil was purchased from oil manufacturers and it was subjected to tansesterfication process to convert it into biodiesel at usable properties. The thermo-physical properties of obtained microalgae biodiesel were measured at ITA labs, Chennai. Desired test samples were prepared in the range 10%–30% and designated as MME10D90 (10% Microalgae methyl ester + 90% fossil diesel), MME20D80 (20% Microalgae methyl ester + 80% fossil diesel) and MME30D70 (30% Microalgae methyl ester + 70% fossil diesel) then the engine is allowed to run with these blends at rated rpm by varying loads from zero – full load. Observations were noted at each load, analyzed and discussed.

MATERIALS AND METHODS

Biodiesel Preparation

The most reliable and easy to convert the crude oil into biodiesel is transesterification process. 1000 ml of raw microalgae oil is taken in a round bottom flask. 12 grams of KOH as alkaline catalyst and 250 ml of methanol taken in a separate beaker and stirred until KOH is completely dissolved in methanol. Round bottom flask with raw oil is heated with continuous stirring to 60^0C, after ensuring the required temperature, KOH-Methanol solution is poured into raw oil. Oil-KOH-Methanol solution is stirred at 720 rpm for two hours at temperature 60^0C, thereafter transfer the solution into another vessel and allow it to cool till two layers are formed. Top layer is microalgae biodiesel and bottom layer is glycerin, both are separated and biodiesel is heated for a while at 100^0C to remove water particles associated with MME, now it is preserved for its usage as biodiesel in diesel engine. The physico-chemical properties of microalgae methyl ester are tabulated in the table 1.

Table 1: Physico-chemical Properties of Microalgae Biodiesel

Fuel Property	Diesel Fuel ASTM(D975)	Biodiesel ASTM(D6751)	MME
Density (Kg / m^3)	820 - 860	860 - 900	876
Kinematic Viscosity @ 40^0C (mm^2 / S)	2.6 – 5.7	1.9 – 6.0	5.32
Flash Point (^{0}C)	60 - 80	Min.130	178
Cetane Number	40 - 55	Min.47	46
Calorific Value (Kj / Kg)	42000-46000	---	38945

Experimental Setup

A single cylinder four stroke diesel engine was tested in order to estimate the performance, emission and combustion characteristics when it is powered with diesel and biodiesel blends. The tested engine is TV 1 model kirloskar engine. The engine is coupled to eddy current dynamometer, AVL 444 N five gas analyzer and AVL smoke meter to measure emission concentrations. To measure the combustion parameters it is provided with pressure sensor, TDC encoder, and data acquisition chord escorted by computer. The schematic layout of experimental setup is shown in figure.1 and the corresponding specifications are shown in Table 2, 3, & 4.

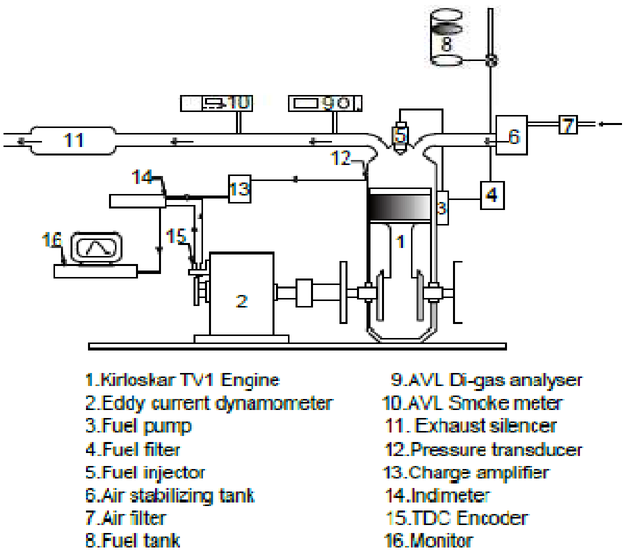

Figure 1: Schematic Layout of Experimental Setup

Table 2: Specifications of the Test Rig

Make	Kirloskar
Model	TV 1
Type	Single cylinder, four stroke, vertical diesel engine
Rated Power	5.12 KW
Rated Speed	1500 rpm
Cylinder bore	87.5 mm
Stroke	110 mm
Compression ratio	17.5 : 1
Cooling	Water cooling
Loading	Eddy current dynamometer

Table 3: Specifications of AVL DI Gas 444 N (Five Gas Analyzer)

Type of Emission	Measuring Range	Accuracy
CO	0.– 15% Vol	+/- 0.02% abs
CO_2	0 – 20% Vol	+/- 0.3% abs
HC	0 – 30000 ppm Vol	+/- 8 ppm
O_2	0 – 25% Vol	+/- 0.02% abs
NO_X	0 – 5000 ppm Vol	+/- 5 ppm

Table 4: Specifications of AVL 437C Smoke Meter

Measurement	Measuring Range	Accuracy
Opacity	0 - 100%	+/- 1%

Experimental Procedure

Firstly allow the engine to run with pure diesel at rated speed (1500 rpm) for few minutes, and then vary the load from zero to full load (0, 25%, 50%, 75% and 100%) note down the readings of performance, emission and combustion parameters at each load. Now repeat the experiment with different prepared test samples such as MME10D90, MME20D80 and MME30D70 and register the parameters as above. Finally the experimental results were analyzed and discussed.

RESULTS AND DISCUSSIONS

Performance Characteristics

Figure 2 represents the change in BSFC (Brake Specific Fuel Consumption) with brake power for diesel and various blends of biodiesel. The BSFC has been decreased with increase in brake power for all the blends comparing to fossil diesel. The main reason for this could be the percentage increase in fuel required to operate the engine is less than that of percentage increase in brake power due to relatively less potion of heat is lost at higher loads. It was observed that, at full load condition the BSFC of MME30D70 is 0.24 Kg/KW–hr and it was reduced by 7.69% compared to conventional diesel.

Figure 3 shows the variation of BTE (Brake Thermal Efficiency) with brake power for diesel fuel and test fuel blends. For all the fuel blends, the BTE increased with increase in brake power. This was due to the fact that, heat loss is reduced with an increase in power. It was noticed that, among all the diesel and biodiesel blends MME30D70 produced maximum BTE with respect to diesel and improved by 14.09 % as the effective combustion took place by the use of rich oxygen content in the biodiesel.

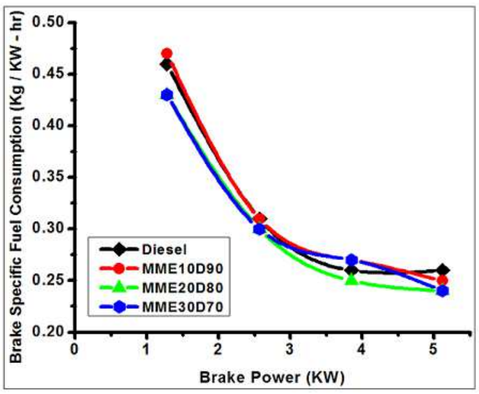

Figure 2: BP Vs BSFC

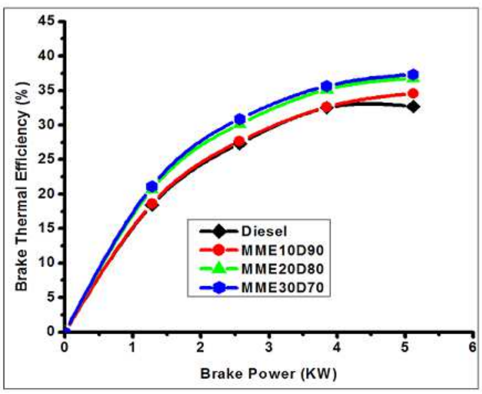

Figure 3: BP Vs BTE

Emission Characteristics

Figure.4 reveals the relationship between exhaust gas temperature and brake power for pure diesel and diesel-biodiesel blends. Generally higher is the exhaust gas temperature, lower is the thermal efficiency of the engine since higher amount of heat energy is wasted through exhaust. From the experimentation it was noticed that, at full load the exhaust gas temperature of MME30D70 is 328.99^{0}C and is reduced by 12.79% when compared to diesel fuel.

Figure.5 illustrates the variation of Carbon dioxide with brake power for tested fuels. As the brake power increases the percentage of CO_2 also increases, this is the principal byproduct of efficient combustion. It was observed that, the percentage of CO_2 in exhaust emission is minimum when the engine was run on MME30D70 and is slightly reduced by 2.71% as compared to pure diesel at full load condition.

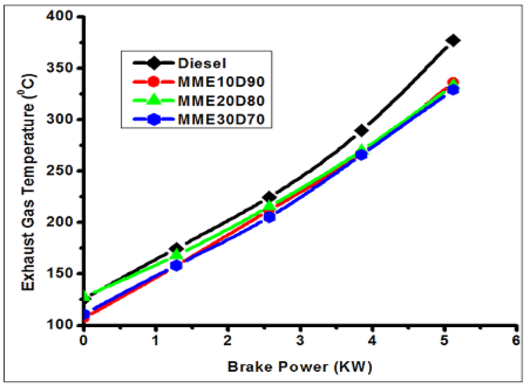

Figure 4: BP Vs Exhaust Gas Temperature

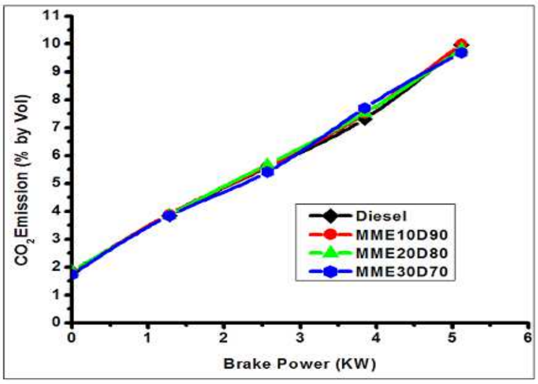

Figure 5: BP Vs Carbon dioxide Emission

Figure 6 depicts the disparity of Carbon monoxide with brake power for all the tested samples. In fact the emission of CO increase with increasing load. As the load increases, rich fuel-air mixture is burned thus forming more CO due to shortage of oxygen. According to the experimental results it was confirmed that, at full load condition CO percentage of MME30D70 was greatly reduced by 71.97% compared to fossil diesel due to rich oxygen content in the biodiesel.

Figure 7 shows the deviation of Unburned Hydro Carbon along with increase in brake power. As per the results obtained during the experimentation, the hydro carbon percentages are increased at each increase in load for diesel as well as for biodiesel. Then it was concluded that, the UHC percentage of MME30D70 is 38 ppm and is reduced by 15.56% when compared to pure diesel.

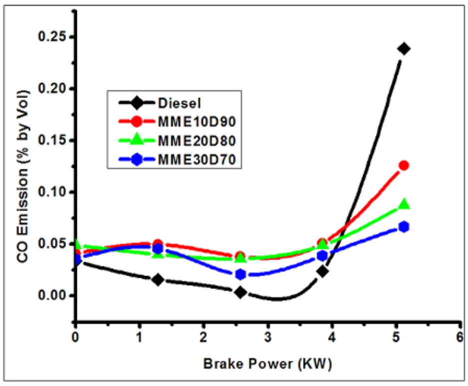

Figure 6: BP Vs Carbon Monoxide Emission

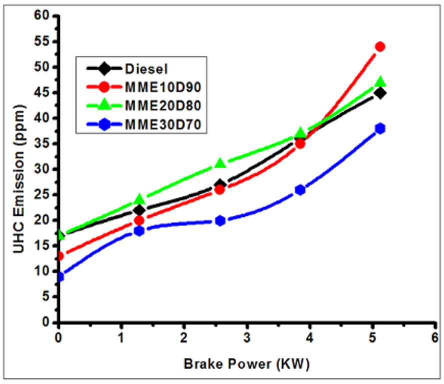

Figure 7: BP Vs Unburned Hydrocarbon Emission

Figure 8 explains the variation of NO_X emission with respect to brake power. In common practice, due to high cylinder pressure and temperature nitrogen can react with oxygen to form oxides of nitrogen. Biodiesel can produce high amount of NO_X as it contains high oxygen content. As per the data it was found that, among all the diesel-biodiesel blends MME10D90 has registered minimum increment at full load condition compared to conventional diesel.

Figure 9 depicts the variation of smoke opacity relating to brake power for all the tested fuels. The percentage of smoke opacity present in the exhaust gas gives the particulate matter present in the exhaust gas. It can be noticed from the figure that the smoke opacity of all the blends is higher than that of pure diesel; this is due to the poor volatility and improper mixing of air and fuel droplets because of higher viscosity of the blends. But at full load, surprisingly MME30D70 has registered less percentage of smoke opacity and is reduced by 10.36% compared to fossil diesel.

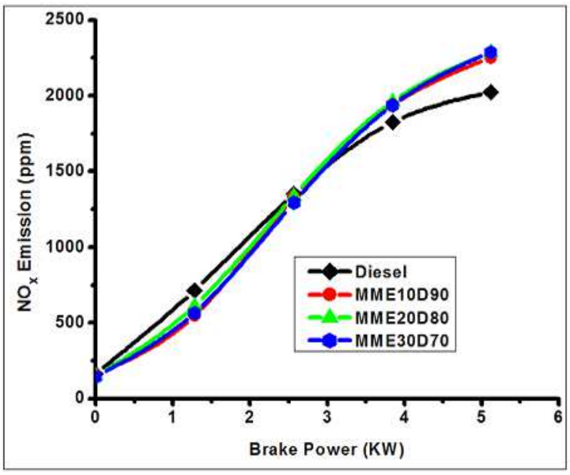

Figure 8: BP Vs Oxides of Nitrogen Emission

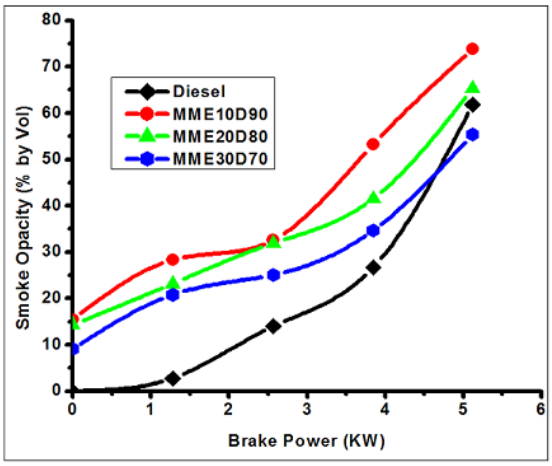

Figure 9: BP Vs Smoke Opacity

Combustion Characteristics

Figure 10 represents the change of Cylinder peak pressure with increase in brake power for all the sample fuels. From the graph it has been witnessed that, the cylinder peak pressure increases steadily with increase in brake power. In general the peak pressure determines the quantity of fuel burned in premixed combustion phase in turn controlled by the ignition delay period. From zero load to full load the cylinder peak pressure was gradually increased and at full load the cylinder peak pressure of MME30D70 is slightly increased by 2.67% compared to pure diesel.

Figure.11 indicates the distinction between Maximum heat release rate and brake power. For all the blends, the maximum heat release rate of biodiesel is less than that of fossil diesel. This is due to the fact that, poor spray atomization as biodiesel posses high viscosity. At full load condition, max. heat release rate of MME30D70 is reduced by 11.7% when compared to conventional diesel.

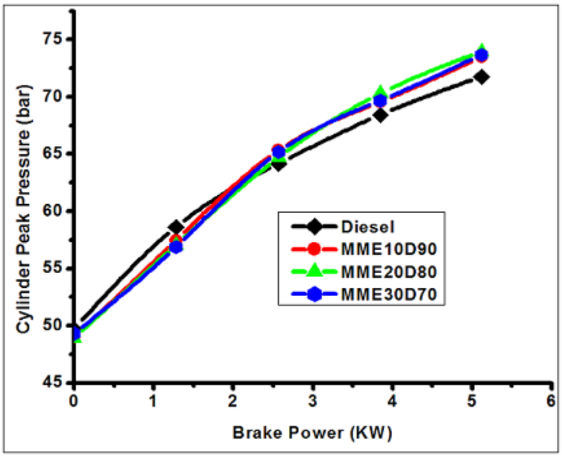

Figure 10: BP Vs Cylinder Peak Pressure

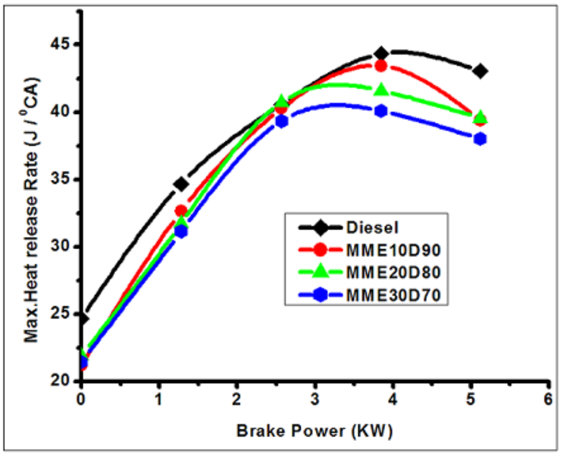

Figure 11: BP Vs Max. Heat Release Rate

CONCLUSIONS

A single cylinder four stroke diesel engine powered with diesel and the blends of diesel and Microalgae Methyl Ester was tested successfully and the experimental results were analyzed and discussed, hence the following conclusions were made,

- BSFC was reduced by 7.69% with MME30D70 at full load condition when compared to fossil diesel.
- At full load condition, when compared to diesel BTE was improved by 14.09% with MME30D70.
- The exhaust gas temperature is lower and it was reduced by 12.79% with MME30D70 at full load condition compared to diesel fuel.
- The percentage of CO_2 is reduced by 2.71% with MME30D70 at full load.
- The percentage of CO is quite low compared to conventional diesel and it was reduced by 71.97% with MME30D70 at full load condition.
- UHC percentage was decreased by15.56% compared to pure diesel with MME30D70 at full load condition.
- NO_X emission of all the biodiesel blends is higher than that of diesel, but MME10D90 shows less amount of NO_X increment compared to diesel fuel at full load condition.
- Off all the biodiesel blends MME30D70 has registered less percentage of smoke compared to pure diesel. At full load condition, the smoke percentage of MME30D70 is reduced by 10.36% compared to fossil diesel.
- At full load condition the peak pressure of the blend MME30D30 is slightly increased by 2.67% than that of fossil diesel.
- Among all the biodiesel blends, the blend MME30D70 shows low max. heat release rate and is reduced by 11.7% compared to pure diesel at full load.

Finally it was resolved that, Microalgae Methyl Ester is the most promising feed stock for producing biodiesel which can be used in compression ignition engines to reduce exhaust emissions and to improve engine performance and it can also be conformed that, 30% microalgae methyl ester blended with 70% pure diesel exhibits better performance,

emission and combustion characteristics without any engine modification. With this optimum blend we can extend the experimentation on the same engine with various injection timings and pressures.

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